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ScienceDirect
Soil & Tillage Research 94 (2007) 410–419
Soil & Tillage Research
www.elsevier.com/locate/still

Soil erosion estimation in conservation tillage systems with poultry litter application using RUSLE 2.0 model

E.Z. Nyakatawa [a,*], V. Jakkula [b], K.C. Reddy [a], J.L. Lemunyon [c], B.E. Norris Jr. [d]

[a] Department of Plant and Soil Science, Alabama A&M University, P.O. Box 1208, Normal, AL 35762, USA
[b] Department of Crop and Soil Sciences, University of Georgia, Athens, GA 30602, USA
[c] USDA/NRCS, 501 W. Felix St., Bldg. 23, Fort Worth, TX 76115, USA
[d] Tennessee Valley Research Station, Belle Mina, AL 35615, USA

Received 29 November 2005; received in revised form 30 August 2006; accepted 7 September 2006

Abstract

Soil erosion is a major threat to global economic and environmental sustainability. This study evaluated long-term effects of conservation tillage with poultry litter application on soil erosion estimates in cotton (*Gossypium hirsutum* L.) plots using RUSLE 2.0 computer model. Treatments consisting of no-till, mulch-till, and conventional tillage systems, winter rye (*Secale cereale* L.) cover cropping and poultry litter, and ammonium nitrate sources of nitrogen were established at the Alabama Agricultural Experiment Station, Belle Mina, AL (34°41′N, 86°52′W), beginning fall 1996. Soil erosion estimates in cotton plots under conventional tillage system with winter rye cover cropping declined by 36% from 8.0 Mg ha^{-1} year^{-1} in 1997 to 5.1 Mg ha^{-1} year^{-1} in 2004. This result was largely attributed to cumulative effect of surface residue cover which increased by 17%, from 20% in 1997 to 37% in 2004. In conventional tillage without winter rye cover cropping, soil erosion estimates were 11.0 Mg ha^{-1} year^{-1} in 1997 and increased to 12.0 Mg ha^{-1} year^{-1} in 2004. In no-till system, soil erosion estimates generally remained stable over the study period, averaging 0.5 and 1.3 Mg ha^{-1} year^{-1}with and without winter rye cover cropping, respectively. This study shows that cover cropping is critical to reduce soil erosion and to increase the sustainability of cotton production in the southeast U.S. Application of N in the form of ammonium nitrate or poultry litter significantly increased cotton canopy cover and surface root biomass, which are desirable attributes for soil erosion reduction in cotton plots.

Keywords: RUSLE 2.0; Conservation tillage; Cover crop; Soil erosion; *C*-factor

1. Introduction

Soil erosion is associated with about 85% of land degradation in the world, causing up to 17% reduction in crop productivity (Oldeman et al., 1990). Despite over 60 years of state and federal soil conservation efforts, soil erosion remains a serious environmental problem in parts of the U.S. (Uri and Lewis, 1998). Worldwide, about 40% of agricultural land is seriously degraded (BBC News, 2000). In addition to land degradation, other problems caused by soil erosion include loss of soil nutrients, declining crop yields, reduction in soil productivity, and pollution of surface and ground water resources by sediment, fertilizer nutrients, and pesticide residues.

Soil erosion also causes air pollution through emissions of radiatively active gases such as carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O)

* Corresponding author. Tel.: +1 256 372 4241; fax: +1 256 372 5429.
E-mail address: ermson.nyakatawa@email.aamu.edu (E.Z. Nyakatawa).

0167-1987/$ – see front matter © 2006 Elsevier B.V. All rights reserved.
doi:10.1016/j.still.2006.09.003

(Lal, 2001; Boyle, 2002). Increased concentration of CO_2, CH_4, and N_2O, also known as ''greenhouse gases'' in the atmosphere is associated with global warming, which leads to an increase in the earth's temperature. Global warming may have far-reaching undesirable effects on weather patterns, forests, agriculture, and water supplies. This will affect the well being of humans and other living organisms.

Some fields in Alabama and Mississippi have been under conventional tillage cotton production for 100 years or more (Bauer and Black, 1983). Cotton is a low residue crop. Therefore, monocropping cotton for an extended period of time has led to soil degradation on cotton farms (Reeves et al., 2002). Although conservation tillage cotton acreage nearly tripled in Alabama and Georgia between 1998 and 2002 (National Cotton Council of America, 2003), about 40% of cotton acreage in north Alabama is still under conventional tillage. Conventional tillage cotton production systems typically include primary tillage with a moldboard or chisel plow in the fall, spring disking or harrowing, and inter-row cultivation for weed control during the crop growing season. These operations promote soil erosion and rapid depletion of soil organic matter (Keeling et al., 1989; Bordovsky et al., 1994).

Conservation tillage systems such as no-till and mulch-till can reduce soil erosion, conserve soil moisture, replenish soil organic matter, and improve crop yields in the long term (Triplett et al., 1996; Reeves, 1997; Nyakatawa et al., 2001; Reddy et al., 2004). Conservation tillage is defined as any tillage and planting system that leaves at least 30% of crop residues on the soil surface after planting (CTIC, 1998). A cover crop, usually grown in winter, is often required to achieve this level of residue cover. In addition to being a low residue producing crop, cotton leaves have lower mulch persistence compared to grass species. It is therefore important to use a suitable cover crop to increase residue production, which will reduce soil erosion in cotton production systems. Winter rye [*Secale cereale* (L.)] possesses many desirable characteristics to be used as a cover crop in cotton production. These include its effectiveness in reducing leaching losses of residual nitrogen, high vigor, winter hardness, early spring growth, and good herbicide sensitivity which enables it to be killed in time for cotton planting.

In addition to being a relatively cheap source of both macro- and micronutrients, animal manure can improve soil tilth due to addition of soil organic matter and enhanced soil microbial activity. Soil organic matter impacts all soil quality functions and soil chemical, biological and physical properties which improve soil resistance to erosion. Poultry litter is available in abundant quantities in the southeast U.S. and its disposal is becoming a problem. Therefore, the use of poultry litter in cotton production serves both as a sustainable utilization of a renewable nutrient resource and also, as an environmentally sound method for disposing of animal waste. The objectives of this study were to investigate the long-term effects of no-till and mulch-till conservation tillage systems with winter rye cover cropping and poultry litter application on soil erosion in cotton plots using the Revised Universal Soil Loss Equation (RUSLE 2.0) computer model.

2. Materials and methods

2.1. Study site and treatments

The experiment was established at the Alabama Agricultural Experiment Station, Belle Mina, AL (34°41′N, 86°52′W), on a Decatur silt loam soil (clayey, kaolinitic thermic, Typic Paleudults) in fall 1996. The study site has a slope of about 1.5% and had been cultivated with cotton under conventional tillage and monocropping for over 10 years prior to the establishment of this experiment. Treatments used in this study consisted of three tillage systems: conventional tillage, mulch-till, and no-till; two cropping systems: cotton in summer followed by winter fallow and cotton in summer followed by winter rye; three N levels: 0, 100, and 200 kg N ha^{-1}; and two N sources: ammonium nitrate and poultry litter. Due to space limitations and operational constraints such as labor and input costs resulting from a larger number of treatments, an incomplete factorial treatment arrangement consisting of 12 treatments, was used (Table 1). Ammonium nitrate was used at one N rate (100 kg N ha^{-1}), which is the recommended rate for cotton in the Tennessee Valley region, while poultry litter was used at 100 and 200 kg N ha^{-1}. Plot size was 8-m wide and 9-m long, which resulted in 8 rows of cotton, 1-m apart. The plots were arranged in a Randomized Complete Block Design with four replications.

Conventional tillage involved tilling the soil to a depth of 25–30 cm using a moldboard plow in November and disking followed by a field cultivator to prepare a smooth seedbed in April. In mulch-till, a Lely rotary cultivator (Lely USA Inc., Wilson, NC) was used to destroy and partially incorporate crop residues to a depth of 5–7 cm before planting. No-till included planting into untilled soil using a Tye (Glascock Equipment and Sales, Veedersburg, IN) no-till planter.

Table 1
List of treatments used in the erosion study at Belle Mina, AL, 1996–2004

Trt. no.	Tillage system	Cropping system	N source	N rate (kg ha^{-1})
1	Conventional-till	Cotton/winter rye	None	0
2	Convention-till	Cotton/winter fallow	Ammonium nitrate	100
3	No-till	Cotton/winter fallow	Ammonium nitrate	100
4	Conventional-till	Cotton/winter rye	Ammonium nitrate	100
5	Conventional-till	Cotton/winter rye	Poultry litter	100
6	Mulch-till	Cotton/winter rye	Ammonium nitrate	100
7	Mulch-till	Cotton/winter rye	Poultry litter	100
8	No-till	Cotton/winter rye	Ammonium nitrate	100
9	No-till	Cotton/winter rye	Poultry litter	100
10	No-till	Cotton/winter fallow	None	0
11	No-till	Cotton/winter rye	Poultry litter	200
12	Bare fallow	Bare fallow	None	0

During the season, a row cultivator was used for controlling weeds in the conventional tillage system, while spot applications of glyphosate [*isopropylamine salt of N-(phosphonomethyl) glycine*] were used to control weeds in the no-till and mulch-till systems. A single operation of row cultivation and herbicide spray were used each year.

The poultry litter used in this study consisted of a combination of chicken (*Gallus gallus domesticus*) manure and bedding materials that was brought from nearby poultry farms. Amounts of poultry litter to supply 100 and 200 kg N ha^{-1} were calculated for application each year based on the N content of the poultry litter. Total N content of poultry litter was determined by the Kjeldhal wet digestion method (Bremner and Mulvaney, 1982) and followed by N analysis using the Kjeltec 1026 N Analyzer (Kjeltec, Sweden) in 1997 and 1998; LECO CNS analyzer (St. Joseph, MI) in 2000 and 2001; and the Vario MAX CNS macro elemental analyzer (Elementar Analysensysteme, GmbH, Germany) in 2003 and 2004. Poultry litter was not applied to the plots in 1999 and 2002, which were planted with corn. A 60% adjustment factor was used to compensate for N availability from poultry litter during the first year (Keeling et al., 1995). The litter was broadcast by hand and incorporated to a depth of 5–8 cm by pre-plant cultivation in conventional tillage and mulch-till systems, whereas in the no-tillage system it was surface applied and not incorporated. The ammonium nitrate and poultry litter were applied to the plots 1 day before cotton planting. Prior to planting, the plots received a blanket application of a P and K fertilizer each year based on soil analyses results, to minimize the effects of P and K applied through poultry litter.

The cropping scheme showing summer rotation of cotton with corn and winter rye cover crop used in this study is presented in Table 2. The winter rye cover crop was planted in fall and killed with glyphosate herbicide about 7 day after flowering in spring of 1997, 1998, 2000, 2001, 2003, and 2004. The time between killing of winter rye and cotton planting was about 4 weeks in each year. The winter rye cover crop (cv. Oklon) was planted at a seeding rate of 60 kg ha^{-1} using a no-till grain drill. The cover crop did not receive any fertilizer to enable it to "scavenge" residual soil nutrients and incorporate them as above ground biomass during the winter season which reduces runoff and/or leaching losses of N.

2.2. Soil erosion estimation

Soil erosion estimation was done using the Revised Universal Soil Loss Equation (RUSLE 2.0) computer model by plot each year in 1997, 1998, 2003, and 2004. RUSLE is an empirically based model founded on the Universal Soil Loss Equation—USLE (Wischmeier and

Table 2
Cropping scheme used in the erosion study, Belle Mina, AL, 1996–2004

Season	Year	Cropping system
Winter/Spring	1996/1997	Winter rye
Summer	1997	Cotton
Winter/Spring	1997/1998	Winter rye
Summer	1998	Cotton
Winter/Spring	1998/1999	Fallow
Summer	1999	Corn
Winter/Spring	1999/2000	Winter rye
Summer	2000	Cotton
Winter/Spring	2000/2001	Winter rye
Summer	2001	Cotton
Winter/Spring	2001/2002	Fallow
Summer	2002	Corn
Winter/Spring	2002/2003	Winter rye
Summer	2003	Cotton
Winter/Spring	2003/2004	Winter rye
Summer	2004	Cotton

Smith, 1978). Renard et al. (1997) modified USLE and developed RUSLE, which has improved means of computing soil erosion factors. RUSLE model enables prediction of an average annual rate of soil erosion for a site of interest for any number of scenarios involving cropping systems, management techniques, and erosion control practices.

2.3. RUSLE model structure

The RUSLE computer model incorporates four physical parameters associated with erosion by water, namely: rainfall erosivity, soil erodibility, topography, and land-use management. Detailed description of the model is presented in Nyakatawa et al. (2001). In RUSLE 2.0 software, information is organized into five main databases, namely: climate, soil, management, vegetation, and residue. The latest version of RUSLE model software (RUSLE Version 2.0) has revised governing equations and an updated database (Bonorino and Osterkamp, 2004).

2.4. RUSLE model C-factor input plant data collection

Immediately after cotton planting, surface residue cover (SRC) in each plot was measured using the camline transect method (Renard et al., 1997). Cotton plant growth data collected for the RUSLE *C*-factor calculation were canopy cover, fall height from the crop canopy, and surface root biomass (top 10 cm of the soil) (RUSLE Users' guide, 2003). Detailed description of data collection methods is given in Nyakatawa et al. (2000, 2001). The data for RUSLE *C*-factor input data calculation were taken every 15 days until crop harvest as per model requirements. In addition to plant data collected for the RUSLE *C*-factor input data given above, biomass data for winter rye, cotton, and corn crops were collected and used in the residue database to account for their contribution to crop residues. RUSLE also requires crop yield data, which was determined by mechanically harvesting open cotton bolls in the central four rows of each plot using a mechanical stripper. Data for cotton yield from this study has been published in Nyakatawa et al. (2000, 2001) and Reddy et al. (2004).

2.5. Weather data for R-factor calculation

Daily weather data needed to calculate the *R*-factor were taken from an automatic weather station at the experiment station. The data consisting of rainfall temperature data (Fig. 1) were entered into the RUSLE model city database to calculate the *R*-factor for the study location.

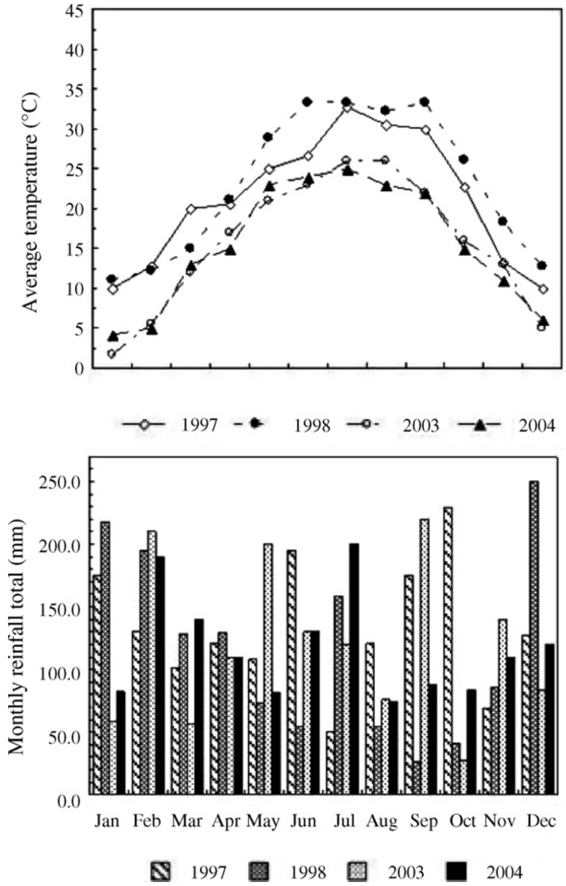

Fig. 1. Total monthly rainfall and mean temperatures at Belle Mina, AL in 1997, 1998, 2003, and 2004.

2.6. Statistical data analyses

The data were statistically analyzed using General Linear Model procedures of the Statistical Analysis System (SAS Version 9.1). Due to the incomplete factorial treatment arrangement used in the study, treatments 2, 3, 4, and 8 were analyzed separately to evaluate tillage × cropping system interaction. Similarly, treatments 4, 5, 6, 7, 8, and 9 were analyzed separately to evaluate tillage × N source interaction. Treatment means for main effect of tillage systems, main effect of cropping systems, and tillage × N source interaction were compared using the least significant difference (LSD) mean separation procedure. Duncan's multiple range test was used to statistically separate the full set of treatment means, which were used to make specific treatment mean comparisons. Correlation analysis was used to determine the association of

SRC, EFH, and crop biomass to RUSLE *C*-factor values and soil erosion estimates. Unless indicated otherwise, significant differences between treatment means were tested at $P < 0.05$ level.

3. Results and discussion

3.1. RUSLE C-factor and soil erosion estimates

There was a significant year × tillage × cropping system interaction on RUSLE *C*-factor values and a significant ($P < 0.001$) tillage × cropping system interaction on soil erosion estimates (Table 3). RUSLE *C*-factor values for cotton–winter rye cropping system under conventional tillage system were 85%, 107%, 134%, respectively, lower than those for cotton–winter fallow cropping system, respectively in 1998, 2003, and 2004 (Table 3). Soil erosion estimates in cotton–winter rye cropping system were 38%, 78%, 105%, and 135%, respectively, lower than those in cotton–winter fallow cropping system under conventional tillage system, in 1997, 1998, 2003, and 2004 (Table 3). These data show that winter rye cover crop has progressively reduced *C*-factor values and soil erosion estimates from 1997 to 2004.

With the exception of 2003, there were no significant differences in RUSLE *C*-factor values and soil erosion estimates between cotton–winter fallow and cotton–winter rye cropping systems under no-till system. Our results are similar to those of Yoo and Touchton (1989) and Yoo and Rochester (1989), who reported that use of wheat cover crop in no-till cotton did not significantly reduce soil loss compared to no-till without a cover crop, but both had lower soil loss than conventional tillage. Stevens et al. (1992) reported that without cover cropping, no-till can reduce soil erosion by 70% compared to conventional till system in cotton.

The pattern of decline in RUSLE *C*-factor values and soil erosion estimates with time from 1997 to 2004 was not observed under cotton–winter fallow cropping system in conventional tillage system or in no-till system. These results can be expected and can be explained by the fact that in conventional till and cotton–winter fallow cropping system, there were no additional crop residues to supplement those produced by cotton. Also, additional crop residues from cotton–winter rye cropping system in no-till system do not impact soil erosion rates as much as they do in conventional tillage system.

RUSLE *C*-factor values in bare fallow plots were, on average two and four times, respectively, greater than those in cotton–winter fallow and cotton–winter rye cropping system under conventional tillage system (Table 3). Similar values under no till system were 5 and 52 times greater, compared to those in cotton–winter fallow and cotton–winter rye cropping systems, respectively. In conventional tillage system, mean soil erosion estimate in cotton–winter fallow cropping system over the study period (11.4 Mg ha^{-1} year^{-1}) was about 50% that for bare fallow plots (24.5 Mg ha^{-1} year^{-1}). Soil erosion estimates in cotton–winter rye cropping system was 6.2 Mg ha^{-1} year^{-1} or about 25% that for bare fallow plots. In no-tillage system, similar values were 5% and 7%, respectively.

Table 3
RUSLE model *C*-factor and soil erosion estimates as influenced by cotton–winter fallow and cotton–winter rye cropping systems under conventional and no-till systems, Belle Mina, AL

Year	Conventional tillage system		No-tillage system		Bare fallow
	Winter-fallow	Winter-rye	Winter-fallow	Winter-rye	
C-factor					
1997	0.1405a†B‡	0.1500aA	0.0165aBC	0.0063aB	0.4500
1998	0.2450bA	0.1325aA	0.0121aC	0.0080aB	0.4500
2003	0.2025bAB	0.0976aB	0.0330bA	0.0082aB	0.4500
2004	0.2175bAB	0.0930aB	0.0215aB	0.0122aA	0.4500
Soil erosion estimate (Mg ha^{-1} year^{-1})					
1997	11.0bA	8.0aA	0.9aB	0.4aA	26.0
1998	10.7bA	6.0aB	0.6aC	0.4aA	20.0
2003	11.7bA	5.7aB	2.2bA	0.6aA	28.0
2004	12.0bA	5.1aB	1.3aB	0.5aA	24.0

† Means for RUSLE *C*-factor or soil erosion estimates under winter-fallow and winter-rye cropping system within a tillage system and year, followed by the same lower case letters (a and c) are not significantly different at the 5% level.

‡ Means for RUSLE *C*-factor or soil erosion estimates in different years within a tillage and cropping system, followed by the same upper case letters (A–C) are not significantly different at the 5% level.

There was a significant tillage × N source interaction for RUSLE *C*-factor values and soil erosion estimates. In conventional tillage system, RUSLE *C*-factor values and soil erosion estimates for plots which received 100 kg ha^{-1} in the form of ammonium nitrate (100AN) were 15% and 32%, respectively, lower than those for plots which received the same amount of N in the form of poultry litter (100PL) (Fig. 2). However, there were no significant differences in RUSLE *C*-factor values between sources of N.

3.2. RUSLE C-factor input data

Results for RUSLE *C*-factor values and soil erosion estimates presented and discussed above can largely be explained by the responses of RUSLE *C*-factor input variables to crop and soil management strategies in different plots. While most of the information required for predicting soil erosion using RUSLE, such as rainfall and soil data do not vary much from plot to plot, the *C*-factor responds directly to yearly variations in crop production systems, such as residue, soil management practices, and tillage systems. The RUSLE *C*-factor accounts for the interactive effects of soil cover, cropping sequences, cultural practices, and length of growing season on the soil erosion process. The responses of RUSLE *C*-factor input variables (surface residue cover, cotton canopy cover, effective fall height, and cotton surface root biomass) to tillage systems, cropping systems, and N treatments used in this study and their influence on RUSLE *C*-factors and soil erosion estimates are discussed in the following sections.

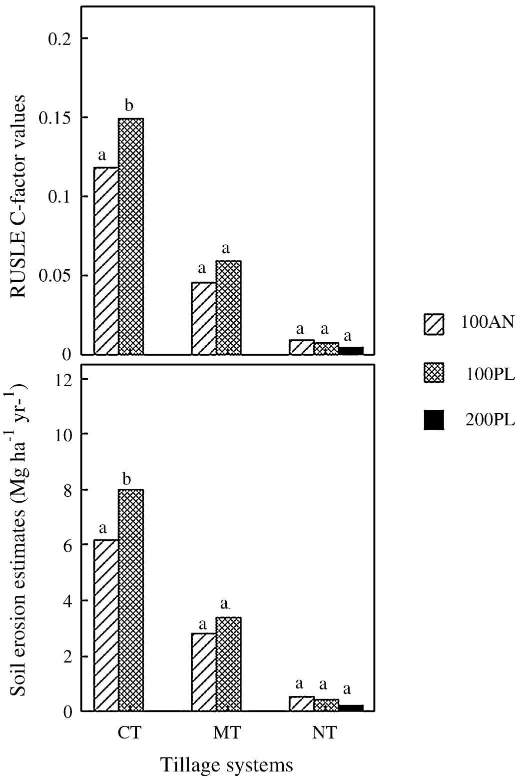

Fig. 2. RUSLE *C*-factor values and soil erosion estimates as influenced by ammonium nitrate (AN) and poultry litter (PL) sources of N under conventional till (CT), mulch-till (MT), and no-till (NT) tillage systems, Belle Mina, AL; 1997–2004 (means for RUSLE *C*-factors or soil erosion estimates for N sources within a tillage system followed by the same letter are not significantly different from each other at the 5% level).

3.2.1. Surface residue cover (SRC)

There was a significant year × tillage × cropping system interaction on percent surface residue cover (SRC) after cotton planting (Table 4). Each year, in conventional tillage or no-till system, SRC in plots which had rye cover crop in the previous winter, was significantly greater than that in plots which were fallow in the previous winter (Table 4). By definition, at least 30% of the soil surface has to be left covered with crop residues after planting in order for any tillage system to be considered as conservation tillage (Conservation Technology Information Center, 1994). In 1997 and 1998, conventional tillage had less than 30% SRC with or without winter rye cover crop. However, it is interesting to note that in 2003 and 2004, SRC in conventional tillage system in plots which had winter rye cover crop was 30% and 37%, respectively, which enabled conventional tillage with winter rye cover cropping to qualify to be considered as conservation tillage.

Visual records showed that crop residues from the rotational corn crop of 1999 were still present in the plots in 2000 and 2001, while crop residues from the

Table 4
Surface residue cover after planting (SRC) as influenced by cotton–winter fallow and cotton–winter rye cropping systems under conventional and no-till systems, Belle Mina, AL

Year	Conventional tillage system		No-tillage system	
	Winter-fallow	Winter-rye	Winter-fallow	Winter-rye
SRC (%)				
1997	1a†B‡	20bB	17aD	100bA
1998	1aB	19bC	13aC	100bA
2003	13aA	30bAB	65aB	94bA
2004	6aAB	37bA	79aA	93bA

† Means for SRC for winter-fallow and winter-rye cropping system within a tillage system and year, followed by the same lower case letters (a and b) are not significantly different at the 5% level.

‡ Means for SRC in different years within a tillage and cropping system, followed by the same upper case letters (A–D) are not significantly different at the 5% level.

corn crop of 2002 were still present in all plots in 2003 and 2004. This explains the increase in surface residue cover in conventional till with winter rye cover cropping and in no-till with winter-fallow cropping (1997 and 1998 versus 2003 and 2004) as shown in Table 4. Halvorson et al. (2002) also found that surface crop residues increased with time under no-tillage with corn rotations due to carry-overs from year to year, but their findings were in a drier, cooler climate in Colorado. It is interesting that we found similar results in a thermic humid regime.

There was no improvement in SRC in conventional tillage with winter fallow cropping to enable it to qualify as conservation tillage. Leaving the plots fallow in winter does not provide the additional crop residues needed to increase SRC. The 6–7% decline in SRC in no-till system with winter rye cover cropping in 2003 and 2004 compared to 1997 and 1998 (Table 4) was attributed to poor winter rye cover crop growth in 2003 and 2004, which was up to 50% lower than that for 1997 and 1998. Carry-over of crop residues from the corn crop of 2002 resulted in significantly greater figures for SRC in conventional tillage with winter fallow cropping (2003) and no-till system with winter fallow (2003 and 2004).

Other benefits of leaving crop residues on the surface after planting include increased water infiltration into the soil and moisture conservation in the seed zone. Naderman (1991) reported that surface residue potentially increases infiltration of water into the soil by 25–50% under no-till compared with a conventional tillage system. Other researchers found that cover crop residues decrease the effect of wind and temperature on soil water evaporation and increases water storage in the soil profile (Smart and Bradford, 1996). Nyakatawa and Reddy (2000) found 38% and 56% increase in soil moisture content in the seedzone during the first 4 days of seedling emergence due to winter rye cover cropping, respectively, in conventional tillage and no-till systems.

According to Moldenhauer et al. (1983), a minimum of 20% soil surface cover is required for a substantial reduction in soil erosion. Also, as SRC approaches 100%, soil erosion declines to a figure close to zero (Moldenhauer and Langdale, 1995). Surface residue intercepts raindrop-impact energy and reduces the flow velocity of runoff water thereby minimizing soil erosion, detachment and transport processes (Cruse et al., 2001). Pimentel (1993) concluded that the cover management factor is the most important factor in minimizing the soil erosion rate.

In our study, SRC was negatively correlated ($P < 0.001$) to RUSLE *C*-factor values and soil erosion estimates (Table 5). Having more crop residues left on the soil surface after planting resulted in reduced soil erosion estimates since the soil is protected from the erosive force of the impact of raindrops and to that of running water. It is evident from Table 5 that the magnitude of the negative correlations between SRC and RUSLE *C*-factor values and soil erosion estimates increased with time from 1997 to 2004, showing a cumulative effect of SRC with time. Therefore, the progressive decline in RUSLE *C*-factor values and soil erosion estimates in cotton–winter rye cropping system under conventional tillage from 1997 to 2004 can largely be attributed to cumulative effects of crop residues on SRC. According to Shelton et al. (1990), surface residue cover serves as a measure of the susceptibility of a field to soil erosion, and is a function of the amount and persistence of crop residue present on the soil surface. Our results demonstrate the important role of SRC in soil and crop management strategies designed to reduce soil erosion in cotton production systems.

Table 5
Pearson correlation coefficients (r) between crop growth parameters and RUSLE model *C*-factor and soil erosion estimates, Belle Mina, AL, 1997–2004

	Surface residue cover (%)	Canopy cover (%)	Effective fall height (cm)	Winter rye biomass (kg ha^{-1})	Cotton surface root biomass (kg ha^{-1})	Cotton biomass (kg ha^{-1})
C-factor						
1997	−0.61***	−0.78***	−0.37*	−0.24NS	−0.76***	−0.76***
1998	−0.68***	−0.76***	−0.75***	−0.44**	−0.58***	−0.62***
2003	−0.81***	−0.83***	−0.81***	−0.48***	−0.71***	−0.69***
2004	−0.84***	−0.74***	−0.79***	−0.39**	−0.77***	−0.78***
Soil erosion estimate (Mg ha^{-1} year^{-1})						
1997	−0.64***	−0.77***	−0.38**	−0.31*	−0.77***	−0.78***
1998	−0.68***	−0.76***	−0.74***	−0.43**	−0.58***	−0.62***
2003	−0.80***	−0.84***	−0.82***	−0.47***	−0.71***	−0.68***
2004	−0.84***	−0.74***	−0.78***	−0.39**	−0.77***	−0.78***

Asterisks (*), (**) and (***) significant at the 0.05, 0.01, and 0.001 probability levels, respectively.

3.2.2. Canopy cover

There was a significant year × N source interaction on cotton canopy cover measured at boll maturity (data not shown). With the exception of 1998, canopy cover for cotton plants in plots which received 100 kg ha^{-1} in the form of ammonium nitrate and 200 kg ha^{-1} in the form of poultry litter (200PL) were significantly higher than that for plants in plots which received 100 kg ha^{-1} in the form of poultry litter. Fig. 3 shows that during the first 45 days after cotton emergence, canopy cover was similar in all plots irrespective of N source. Therefore, during this time, crop residues left on the surface after planting play a very important role in soil erosion reduction. However, from 60 to 120 days after emergence, cotton canopy cover in plots which received 100 kg ha^{-1} in the form of ammonium nitrate or poultry litter and 200 kg ha^{-1} in the form of poultry litter (200PL) were consistently greater than that for plants in plots which did not receive N.

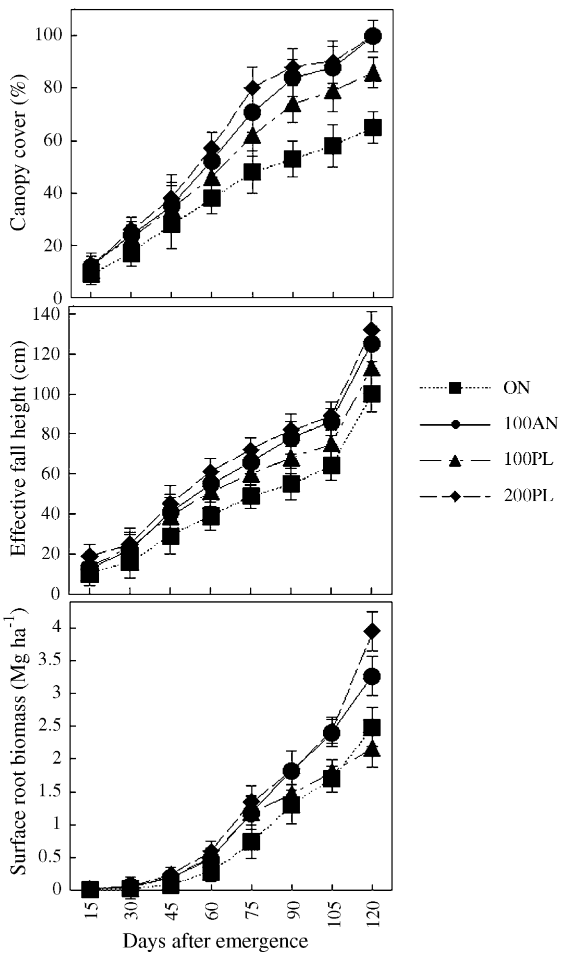

Fig. 3. Canopy cover, EFH, and cotton surface root biomass used as RUSLE *C*-factor input variables at 15 day intervals as influenced by N sources, Belle Mina, AL; 1997–2004 (LSD values of means shown).

The differences in crop responses to 100 kg ha^{-1} in the form of ammonium nitrate and 100 kg ha^{-1} in the form of poultry litter although not significant, were attributed to differences in N availability between ammonium nitrate and poultry litter. Crop residues can cause immobilization of available inorganic N (Green et al., 1995). Application of N in the form of ammonium nitrate can offset the effects N immobilization, whereas more time is needed for N to be released when N is applied in the form of poultry litter. A similar result was obtained in cotton yield responses from ammonium nitrate and poultry litter (Nyakatawa et al., 2000, 2001; Reddy et al., 2004). Although a correction factor was used to account for the slow release of N from poultry litter, it does seem that the availability of N from poultry litter was over-estimated in these situations where considerable surface residues are present as shown by the better response of the crop to poultry litter at 200 kg N ha^{-1}. In Georgia, Endale et al. (2002) reported no significant differences in cotton yields between poultry litter and inorganic fertilizer.

Unlike crops such as cereals and grain legumes, cotton is generally planted in wide rows of about 1 m apart. This leaves most of the inter-row spacing exposed to direct impact of raindrops, especially early in the growing season. Energy from the direct impact of raindrops on the soil surface is a major factor causing disintegration of soil structure and the break up of soil particles generating sediment. Therefore, the establishment of a widely distributed crop canopy cover is very critical for cotton in terms of soil erosion reduction. A good canopy cover gives soil better erosion protection by absorbing the energy from falling raindrops from rainfall or irrigation which accounts for most of the erosion. Since cotton canopy cover was negatively correlated ($P < 0.001$) with RUSLE *C*-factor values and soil erosion estimates (Table 5), better canopy growth accounts for the significantly lower RUSLE *C*-factor values and soil erosion estimates for plots which received 100 kg ha^{-1} in the form of ammonium nitrate compared to those for plots which received the same amount of N in the form of poultry litter.

3.2.3. Effective fall height (EFH)

Effective fall height (EFH) for cotton, which is the distance a raindrop falls after striking the crop canopy was negatively correlated to RUSLE *C*-factor values and soil erosion estimates (Table 5). This should not be interpreted to suggest that with greater EFH, soil erosion becomes less. Rather, it is a result of the fact that plots in which cotton plants performed better in terms of growth parameters such as plant height and biomass due to factors like no-till and cover cropping, also had low values of RUSLE *C*-factors and hence soil erosion rates. There were no significant tillage or cropping system effects on EFH. However, from 60 to 120 days after emergence, EFH for cotton plants in plots which received 100 kg ha^{-1} in the form of ammonium nitrate and 200 kg ha^{-1} in the form of poultry litter were generally greater than that for plants in plots which did not receive N and sometimes, those which received 100 kg ha^{-1} N in the form of poultry litter (Fig. 3). However, despite the greater EFH in plots which received 100 kg ha^{-1} in the form of ammonium nitrate compared to those which received the same amount of N in the form of poultry litter, RUSLE *C*-factors and soil erosion estimates were significantly lower in the former. This shows that the benefits of better plant growth such as better canopy cover and plant biomass in plots which received 100 kg ha^{-1} in the form of ammonium nitrate outweighed the increase in soil erosion due to higher values of EFH.

3.2.4. Surface root biomass

RUSLE 2.0 computer model requires data for surface root biomass (top 10 cm of the soil) every 15 days as input data for the *C*-factor calculation. There was a significant effect of cropping systems and significant year × tillage and year × N source interactions on surface root biomass of cotton (data not shown). Mean cotton surface root biomass for in cotton–winter rye cropping system (2.3 Mg ha^{-1}) was 28% greater ($P < 0.005$) than that in cotton–winter fallow cropping system (1.8 Mg ha^{-1}) due to added biomass of cover crop. In 1997, mean cotton surface root biomass in no-till plots was 18% greater than that in conventional tillage system. However, in 1998, mean cotton surface root biomass in no-till system was 30% lower than that in conventional tillage system, while in 2003 and 2004, there were no significant differences in mean cotton surface root biomass in no-till and conventional tillage systems.

As with canopy cover, in terms of soil erosion control, the rate development of root biomass with time from seedling emergence is more important than the final root biomass at maturity in cotton, since the soil is more susceptible of erosion during the early stages of crop growth. Fig. 3 shows the response of cotton root biomass in the top 10 cm of the soil to N sources at 15 day intervals after seedling emergence. From about 75–120 days after emergence, cotton surface root biomass for plants in plots which received 100 kg N ha^{-1} in the form of ammonium nitrate and those which received 200 kg N ha^{-1} in the form of poultry litter was greater than that for plants in plots did not receive N and from 105 to 120 days after emergence, greater than those which received 100 kg N ha^{-1} in the form of poultry litter (Fig. 3). As with canopy cover and EFH, the differences in crop response to 100 kg N ha^{-1} in the form of ammonium nitrate and 100 kg N ha^{-1} in the form of poultry litter can be attributed to differences in N availability between ammonium nitrate and poultry litter as explained earlier.

Plant roots can physically hold the soil particles together. In addition roots and crop residues exude binding agents and serve as a food source of microbes which increase soil aggregation and there by reducing the runoff. Plant roots can greatly enhance soil stability and anti-erodibility (Zhou and Shangguan, 2005). Cotton surface root biomass was negatively correlated ($P < 0.001$) to RUSLE *C*-factor values and soil erosion estimates (Table 5). Therefore, crop and soil management strategies which result in the rapid development of surface roots will reduce soil loss by erosion. Table 5 shows that RUSLE *C*-factor values and soil erosion estimates were negatively correlated to cotton biomass in each year and to winter rye biomass in 1998, 2003, and 2004. The non-significant correlation between winter rye biomass and RUSLE *C*-factor values and soil erosion estimates in 1997 was attributed to the fact that winter rye biomass data for 1997 was for the crop that was planted in fall 1996 before the establishment of the treatments. As a result, winter rye biomass data were similar for all the treatments in 1997.

4. Conclusions

Our study shows that continuous additions of crop residues are critical for reducing soil erosion and to increase the sustainability of cotton production in the southeast U.S., particularly in conventional tillage system. Based on RUSLE 2.0 model predictions, soil erosion estimates in no-till system were significantly lower than those in conventional tillage, with or without winter cover cropping. Application of N in the form of ammonium nitrate or poultry litter significantly increased cotton canopy cover and surface root biomass, which are desirable attributes for soil erosion reduction in cotton plots. Use of poultry litter as a source of N in cotton production systems may provide an environmentally sound strategy for waste disposal in the southeast U.S., where excess poultry manure is becoming an environmental problem.

Acknowledgements

The authors are grateful to USDA/CSREES for funding this research project. Our special thanks and appreciation go to Dr. Daniel Yoder, University of Tennessee, Knoxville for providing the project with the RUSLE Version 2.0 computer model.

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